Three-dimensional echocardiography improves the understanding of left atrioventricular valve morphology and function in atrioventricular septal defects undergoing patch augmentation

Catherine Barrea, MD*
Stéphanie Levasseur, MD
Kevin Roman, MB, CHB
Masaki Nii, MD
John G. Coles, MD
William G. Williams, MD
Jeffrey F. Smallhorn, MBBS

Objectives: We sought to address the role of 3-dimensional echocardiography in the evaluation of the left atrioventricular valve in children with an atrioventricular septal defect who underwent patch augmentation of their valve for either regurgitation or left ventricular outflow tract obstruction.

Methods: Five children whose ages ranged between 4.5 and 9.2 years and who underwent patch augmentation of their left atrioventricular valve had a preoperative and postoperative transesophageal echocardiogram with 3-dimensional reconstruction to evaluate the left atrioventricular valve. The indication for operation was left atrioventricular valve regurgitation in 3 patients and left ventricular outflow tract obstruction in 2 patients. Three were rerepairs, and 2 were primary repairs. Both 3-dimensional morphology and color Doppler data were obtained. Two- and 3-dimensional findings were correlated with surgical observations through the use of direct inspection and video images obtained with a head-mounted super-VHS camera.

Results: In each case there was precise correlation between the 3-dimensional and surgical findings as to the cause of leaflet failure in those with regurgitation. The site that would require leaflet augmentation could be determined by means of 3-dimensional echocardiography. Three-dimensional echocardiography provided more specific detail as to the morphology and function of the left atrioventricular valve than did its 2-dimensional counterpart.

Conclusions: Three-dimensional echocardiography provides detailed information about the status of the left atrioventricular valve in the atrioventricular septal defect and can aid in the planning of either primary or secondary repair.

From the Divisions of Cardiac Surgery and Cardiology of The Hospital for Sick Children and the University of Toronto, Toronto, Ontario, Canada.

Drs Barrea and Roman are supported by a grant from the Ontario Consortium of Cardiac Imaging.

Received for publication March 12, 2004; revisions received July 6, 2004; accepted for publication July 14, 2004.

Address for reprints: Jeffrey F. Smallhorn, MD, FRCPC, The Hospital for Sick Children, Division of Cardiology, 555 University Ave, Toronto, Ontario, Canada M5G 1X8 (E-mail: jsmallho@sickkids.ca)

*Dr Barrea is currently affiliated with the Cliniques Universitaires Saint Luc, UCL, Brussels, Belgium.

J Thorac Cardiovasc Surg 2005;129:746-53

0022-5223/$30.00

doi:10.1016/j.jtcvs.2004.07.023

Despite continuous improvement in surgical techniques, early and late left atrioventricular valve (LAVV) failure remains a challenge in patients with atrioventricular septal defects (AVSDs).[1-4] In addition, the development of left ventricular outflow tract (LVOT) obstruction complicates approximately 4% to 12% of cases.[5] This is in part due to the intimate relationship between the LAVV and the LVOT in AVSDs in conjunction with other morphologic substrates for obstruction. Two-dimensional (2D) transthoracic echocardiography is an excellent tool to define the basic morphologic features of AVSD[6] and provides sufficient global preoperative data in the majority of cases.[7] However, it might be difficult to define the precise mechanisms of valve failure. Three-dimensional (3D) echocardiography is a new technique that has been shown to be useful in the assessment of the mitral valve[8-10] and might play a key role in the preoperative assessment of the LAVV in patients with an AVSD either before or after surgical repair.

Parallel to the development of new diagnostic tools, surgical techniques are also continuously evolving. Given the close relationship between the LAVV and the LVOT, enlargement of the LVOT by means of fibromyomectomy was associated with leaflet augmentation, as has been previously described.[4,11] Recently, a novel surgical technique has been described by Poirier and associates,[4] with emphasis on the benefit of pericardial patch augmentation of the LAVV in cases with a dysplastic LAVV and regurgitation.

We present the use of 3D echocardiography in the preoperative evaluation of the left atrioventricular valve in 5 patients with AVSDs in whom pericardial leaflet augmentation was undertaken.

Methods

Five patients underwent TEE with a Sonos 5500 (Philips Medical Systems) with a Philips Omniplane 6.2-5 MHz probe (Philips) that is interfaced with online software that collects a 3D data set. The use of transesophageal 3D echocardiography in the preoperative and postoperative assessment of patients with AVSDs was approved by the ethics committee at the Hospital for Sick Children, Toronto. All 5 patients were deemed to require surgical intervention on the basis of standard clinical and echocardiographic findings. Preoperative and postoperative echocardiography was performed in the operating room after achievement of general anesthesia before and after chest closure in 4 patients, whereas in 1 patient preoperative 3D echocardiography was performed as an outpatient procedure a few weeks before the operation. A 3D data set could not be obtained during the immediate postrepair period because of patient instability. This patient had a standard TEE with 2D imaging to assess the immediate result of the repair and a repeat 3D TEE evaluation of the LAVV 2 months later. For each case, standard 2D TEE images with color Doppler scanning of the LAVV were obtained for comparison.

Three-dimensional data sets were acquired by using the rotational device built into the Omniplane probe, which collects data at 3° increments around a 180° arc, providing 61 sequential images. Respiratory and electrocardiographic gating was used to obtain optimal temporal and spatial registration. A complete cardiac cycle was recorded at the end of expiration. In all cases, adequate data sets were obtained, in part because of the stable heart rate and respiration that were controlled during anesthesia. Images were obtained both in gray scale and with color Doppler mapping. The acquisition and storage time per data set varied from 3 to 4 minutes, depending on the heart and respiration rate. The raw data were initially stored on a magneto-optical disk and subsequently transferred to a commercially available workstation (TomTec Echoview 4.2 and, more recently, TomTec Cardio-View RT) for postprocessing and 3D reconstruction, as previously described.[10]

From the postprocessed 3D data sets, new cut planes in any orientation were chosen, and volume-rendered 3D images of the LAVV were obtained. Mainly en face views of the LAVV from the left atrium (from above) and the left ventricle (from below) were reconstructed to determine the precise anatomy of the valve leaflets, the sites, and the mechanisms of LAVV regurgitation. The 3D images, as seen from above the valve, were displayed in a surgical view. Color Doppler images were adjusted such that the proximal isovelocity jet, which is the site of flow acceleration proximal to the defect in the valve; the vena contracta (this represents the regurgitant jet as it traverses the defect in the valve); and the aliased jets above could be identified in a precise relationship to the LAVV. Once the color jet was optimized, the valve image could be retained or removed to image the exact appearance and size of the vena contracta.

For patients 1, 3, 4, and 5, the surgical procedure was recorded with a head-mounted super-VHS camera, which permitted confirmation of the 3D reconstructed images and surgical findings. For patient 2, only the surgical description of the valve was available. Frame-by-frame analysis of the surgical images was undertaken to obtain precise anatomic detail and mechanisms of valve failure. The echocardiographic and surgical images were then correlated to ensure that the 3D reconstructed images were a true representation of the pathologic findings. The subsequent echocardiographic images were displayed in a surgical orientation.

Although the 3D images could be displayed as seen in the beating heart, the surgical views of the valve were sometimes distorted as the surgeon manipulated the valve. As a result, it was difficult to obtain all of the surgical detail in a single image, and hence the subsequent figures represent a combination of images of the valve as seen by the surgeon. Also, although the echocardiographic images that are subsequently displayed for publication are in a 3D format, they were in fact seen in the fourth dimension (4D; ie, over time by the echocardiographer). During data analysis, the echocardiogapher had the ability to rotate the 3D or 4D data set to obtain a variety of views of the valve.

Results

The children's ages and weights at operation ranged from 4.5 to 9.2 years and 18.3 to 28 kg, respectively. Patients 1 and 2 underwent a primary repair with patch augmentation of the LAVV, whereas patients 3, 4, and 5 had undergone prior repair between 6 and 7.5 years after their initial procedure. Left atrioventricular valve repairs were performed as described by Poirier and associates[4] with a glutaraldehyde-treated (patients 1 and 2) or an untreated (patients 3, 4, and 5) autologous pericardial patch.

Table 1 details the preoperative 2D and 3D echocardiographic findings, the surgical procedures performed, and the immediate postoperative findings. In general, there was a better correlation between the 3D and surgical findings than those observed with 2D echocardiography. Three-dimensional echocardiographic images provided new details about the extent of the cleft, left atrioventricular valve orifice, and commissures and leaf-

CHD

TABLE 1. Initial diagnosis, demographic data, surgical procedures, indications for current surgical procedure, and echocardiographic findings

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Diagnosis	Partitioned AVSD with DOLAVV and LVOT obstruction	Partitioned AVSD	Postoperative partitioned AVSD	Postoperative complete AVSD, LVOT obstruction	Postoperative partitioned AVSD, DOLAVV, mild LVOT obstruction
Age at prior procedure			Closure of primum ASD and cleft closure (15 mo)	Double-patch repair and cleft closure (5.5 mo)	Closure primum ASD and cleft closure (5 mo)
Indications for further operations	LVOT obstruction, moderate LAVV regurgitation	Moderate LAVV regurgitation	Moderate LAVV regurgitation	Complex LVOT, Obstruction, and mild regurgitation	Moderate LAVV regurgitation
Preoperative 2D echo	DOLAVV with moderate regurgitation through the cleft, LVOT obstruction caused by a subaortic ridge and secondary chordae	Moderate central regurgitation through large cleft, leaflets coapt poorly	Moderate regurgitation through residual cleft with less significant medial and lateral leaks	Mild central LAVV regurgitation, LVOT obstruction caused by tunnel narrowing, subaortic ridge, and accessory LAVV tissue	Double-orifice LAVV with a small post orifice; severe regurgitation through residual cleft, with less through post orifice, LVOT obstruction caused by fibromuscular ridge and secondary chords
Preoperative 3D echo findings	Large cleft, double-orifice LAVV, good-sized commissures with a moderate leak through superior orifice, LVOT obstruction caused by subaortic ridge and accessory chordae	Partial cleft, good-sized commissures, severe regurgitation caused by poor coaptation between partially fused superior and inferior leaflets and the mural leaflet	Tiny residual cleft, regurgitation through perforation at cleft base, severe regurgitation at the site of the deficient inferior commissure caused by abnormal mural leaflet	Tiny residual cleft, LVOT obstruction caused by tunnel narrowing, circumferential ridge, tissue tag, well-formed commissures	Double-orifice LAVV, smaller orifice in IBL, severe regurgitation caused by cleft and poor coaptation after fusion of superior and mural leaflets, mild regurgitation at inferior commissure, second orifice competent
Surgical procedures	Resection fibrous tissue and chordae in LVOT, patch enlargement of the SBL and IBL, closure of the cleft in the major orifice	Patch enlargement of SBL and IBL, closure of small residual cleft	Closure of the hole at base of prior cleft, commissuroplasty, patch extension of LAVV between IBL and ML	Resection of subaortic ridge, chordae, split abnormal papillary muscle, modified Konno, patch enlargement of SBL and IBL, closure of tiny cleft	Closure of residual cleft, patch augmentation of SBL-IBL, resection of fibromuscular subaortic ridge and accessory chords
Immediate postoperative 3D echo findings	Mild LAVV regurgitation, no stenosis, no significant LVOT obstruction	Mild regurgitation at inferior commissure, no stenosis	Mild LAVV regurgitation (centrally and between SBL-mural leaflet), no stenosis	Unobstructed LVOT, no LAVV regurgitation or stenosis	Unobstructed LVOT, mild LAVV regurgitation on 2D echo study and subsequent 3D echo, no stenosis

AVSD, Atrioventricular septal defect; *DOLAVV,* double-orifice left atrioventricular valve; *2D,* 2-dimensional echocardiography; *echo,* echocardiography; *ASD,* atrial septal defect; *LVOT,* left ventricular outflow tract; *LAVV,* left atrioventricular valve; *3D,* 3-dimensional; *IBL,* inferior bridging leaflet; *SBL,* superior bridging leaflet; *ML,* mural leaflet.

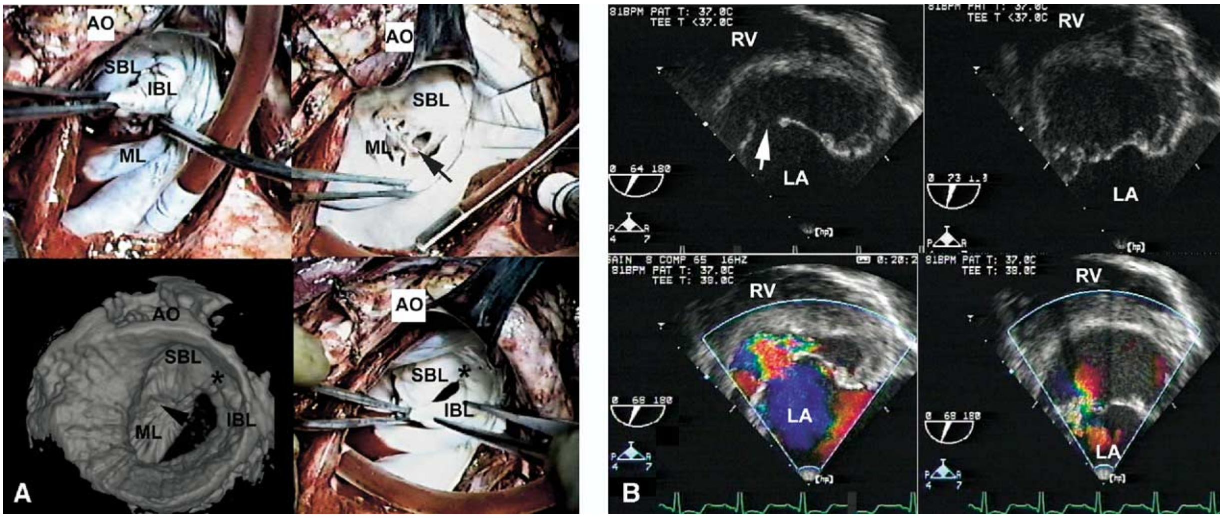

Figure 1. A, This montage is from patient 5 with a residual cleft, leaflet deficiency, and fusion of the superior bridging and mural leaflet commissure to the subvalvular apparatus. The *upper left image* is a surgical view of the inferior and mural commissure. The position of the aorta with respect to the superior mural leaflet has been superimposed on the surgical image. Note that the region of the cleft has been shifted to view the commissure. The *top right image* shows the fusion of the mural and superior leaflets to the subvalvular apparatus. The *bottom right image* is the surgical view of the residual cleft. The *bottom left image* is the 3D image of the LAVV as seen from above and oriented in a surgical view. Note the keyhole configuration of the orifice caused by the fusion of the superior and mural leaflets, which is indicated by the *black arrow* and corresponds to the *black arrow* in the *upper right image*. The residual cleft is indicated by the *asterisk* and corresponds to the surgical image in the *lower right image*. *AO*, Aorta; *IBL*, inferior bridging leaflet; *ML*, mural leaflet; *SBL*, superior bridging leaflet. B, This montage demonstrates the TEE findings in patient 5. The *left panel* shows the residual cleft seen in diastole, with the *right panels* demonstrating the systolic appearance of the valve. Note that in comparison with Figure 1, *A*, Figure 2, and Figure 3, specific detail is lacking in the 2D image. *LA*, Left atrium; *RV*, right ventricle.

let deficiency (Figures 1 and 2). In addition, in patients 1 and 5 with a double-orifice left atrioventricular valve, it was possible to demonstrate the precise location of the second orifice. The addition of color flow Doppler scanning superimposed on or isolated from the 3D image permitted a precise localization of the regurgitant jets in 3 dimensions, as well as the size of the vena contracta (Figure 2).

Patient 3 had a large posteroinferior leak caused by a deficiency of the inferior mural commissure, as well as a smaller regurgitant jet caused by a hole at the base of the previous cleft repair (Figure 2). Patient 2 had an important central leak, which was reduced to mild status after patch augmentation (Figure 3), whereas in patients 1 and 4 there were small central leaks because the major lesion was the LVOT obstruction. Patient 5 had a large leak in the region of the cleft between the superior and inferior leaflets, which was compounded by the fusion of the superior and mural commissure to its subvalvular apparatus. This resulted in the 3D appearance of a keyhole bileaflet main orifice (Figure 1). In addition, the secondary regurgitant jet arose from the inferior commissure and not the smaller secondary orifice, as suggested by the 2D study. Of note at the time of saline testing, the secondary orifice was competent, and the postoperative color Doppler scan demonstrated no regurgitation from this site.

Discussion

AVSD is a common congenital cardiac malformation. The surgical mortality has dramatically decreased over time.[12,13] Despite improved early survival, long-term morbidity of the LAVV remains an important concern.[1-4] Primary surgical repair is relatively straightforward in the majority of cases and involves patching any atrial or ventricular communication and closure of the cleft between the superior and inferior bridging leaflets. On the other hand, reoperation for subsequent LAVV failure is often more complex and might involve annular reduction, commissurotomy, closure of a residual cleft, and, more recently, patch enlargement of the LAVV in cases in which there is leaflet deficiency. Although the surgeon has the opportunity to inspect the LAVV and test its competency with saline, this latter technique is nonphysiologic and might provide an incomplete evaluation of the true nature of the valve failure.

Two-dimensional echocardiography with color Doppler scanning is the current standard for both preoperative and

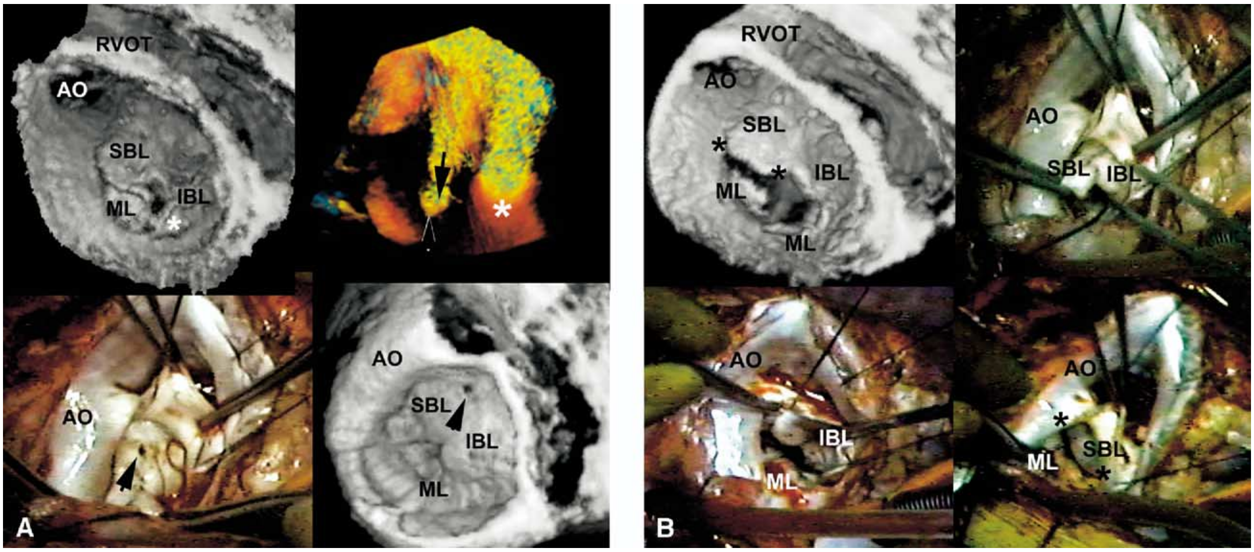

Figure 2. A, This montage is from patient 3 and demonstrates the sites of regurgitation. Note the residual hole in the surgical image at the base of the repaired cleft in the *lower left panel*, as indicated by the *black arrow*. The position of the aorta has been superimposed on the surgical image. This corresponds to that seen by means of 3D echocardiography in the *lower right panel*, as imaged from above in a surgical view. The *upper left image* is the LAVV as seen from below during systole. Note the residual defect in the vicinity of the inferior and mural leaflets, as indicated by the *white asterisk*. The *upper right panel* represents the 2 regurgitant jets with the tissue stripped away. Note the smaller jet *(black arrow)* from the residual hole and the larger jet *(white asterisk)* from the posteroinferior region. *AO*, Aorta; *IBL*, inferior bridging leaflet; *ML*, mural leaflet; *RVOT*, right ventricular outflow tract; *SBL*, superior bridging leaflet. B, This panel of images is also from patient 3 and demonstrates the commissures of the LAVV as seen from a surgical and 3D perspective (diastolic view from below by means of echocardiography). Note the well-formed commissure between the superior and mural leaflets, both in the surgical image in the *lower right panel* and the 3D image in the *upper right panel*, which are seen between the 2 *asterisks*. The *lower and upper left panels* show the poorly formed inferior and mural commissure, which was the site of the major regurgitant jet. Also note the tiny residual cleft in the LAVV. The position of the aorta has been superimposed on the surgical view. *AO*, Aorta; *IBL*, inferior bridging leaflet; *ML*, mural leaflet; *RVOT*, right ventricular outflow tract; *SBL*, superior bridging leaflet.

postoperative assessment of patients with AVSD.[6,7] The technique provides accurate data before primary repair, particularly because in the majority of cases there is minimal incompetence of the LAVV. In postoperative LAVV failure, the questions asked are more specific and challenge the 2D technique. Although important information can be gleaned from the study as to the possible mechanisms of valve failure, specific detail is frequently lacking, leaving the final decision as to the precise mechanism to the surgeon. This limitation is due to the difficulty in a 2D perspective of providing fine details regarding the status of the commissures, the precise location of regurgitant jets, the extent of a residual cleft, and sites of poor coaptation in patients with associated valve dysplasia. Color Doppler scanning is a helpful adjunct; however, the true extent and location of the regurgitant jet or jets might be difficult to appreciate in a 2D image, particularly in cases with multiple jets caused by the phenomena of jet entrainment. As a result, it is often difficult to impart a clear picture to the nonechocardiographer or surgeon.

Three-dimensional echocardiography is an emerging technique with tremendous potential in patients with atrioventricular valve failure. Previous investigators[14] have demonstrated that it is feasible to reconstruct the atrioventricular junction from en face views in human heart specimens with AVSD by immersing them in a water bath. Early transthoracic[15] rotational 3D ultrasound probes have been used to obtain basic anatomic detail in patients with AVSD. Earlier probes, although a step in the right direction, lacked the spatial resolution that is needed to provide detailed information about the LAVV in AVSDs. Nor did they have the capability to assess color Doppler scanning in 3 or 4 dimensions.

Acar and coworkers[16] assessed leaflet area in 27 patients after AVSD repair and correlated the origin of the regurgitant jet to the relative surface of the inferior bridging leaflet and the mural leaflet. The inferior bridging leaflet was smaller in patients with LAVV regurgitation through the cleft (medial), and the mural leaflet was smaller in cases of lateral regurgitation originating from the region toward the mural leaflet. There was no significant correlation between the severity of the LAVV regurgitation and the leaflet area ratios. However, they used 2D and not 3D color Doppler scanning to localize the origin of the regurgitant jet, and they did not correlate their findings with surgical observations. Also, 21 of the 27 studies were transthoracic studies, which do not provide data sets as clear as those seen with TEE. Indeed, they were able to assess the relative surface areas in 6 of 6 TEEs but only in 21 of 27 transthoracic echocardiographic studies.

In adults the mitral valve has been studied quite extensively by using 3D techniques. De Simone and associates[17] evaluated 69 patients with mitral valve regurgitation with 3D color Doppler scanning to determine the origin of regurgitant jets and jet volumes. Other groups have been interested in the shape and motion of the annulus of the mitral valve and its relationship to valve function. Otsuji and colleagues[9] developed animal models of mitral valve regurgitation in global and segmental left ventricular dysfunction. They demonstrated that global and segmental left ventricular dysfunction, even severe dysfunction, without ventricular dilatation does not produce mitral valve regurgitation and that mitral valve regurgitation correlates with changes in the 3D geometry of the subvalvular apparatus and the annulus. Important practical implications were drawn from this information regarding approaches to restore a more favorable geometry and might explain why, in some cases, a simple annuloplasty ring might fail to improve mitral valve regurgitation. More recently, 3D TEE techniques were used in a similar fashion to our study in adults with various types of valve native and prosthetic mitral valve failure.[10] Of note, these patients did not have surgical correlation of their findings.

The technique of data acquisition is also changing. In our study and in many of those published thus far, data have been acquired by using a variety of TEE and transthoracic echocardiographic techniques. Transesophageal acquisition of 3D data sets with a rotational device was the technique chosen by us. At present, this approach probably still provides the best data sets because there is no interposition of the ribs or lungs in the data set. A high-frequency transducer is used, which also optimizes the image quality in children. Although heart rate and respiratory gating are necessary, they ensure an excellent data set, particularly when both are kept constant during anesthesia. More recently, real-time 3D echocardiography has become available[18]; however, this is still in its early stages, with a transducer that is currently designed for adults and not children. Studies are still subject to all the limitations of transthoracic echocardiography; however, if a good ultrasound window is present, it is possible to obtain instantaneous 3D images that are not dependent on respiratory or electrocardiographic gating if a narrow sector beam is used. Full volumes for both imaging

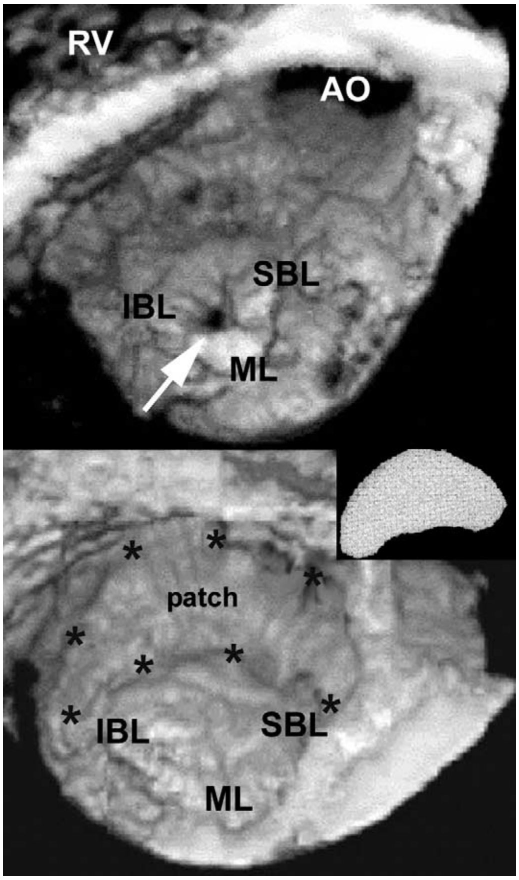

Figure 3. This panel is from patient 2 with the partial cleft between the superior and inferior bridging leaflets. The *upper panel* shows the left atrioventricular valve as seen from below during systole. Note that there is a residual deficiency in the center of the valve caused by poor coaptation of the leaflets. The *lower panel* demonstrates the 3D appearance of the valve after it was patched. Note the crescent-shaped template that was used to fashion the patch, which can be seen in the 3D image, as outlined by the *asterisks*. Note how the valve coapts well and that there was minimal residual regurgitation. *AO*, Aorta; *ML*, mural leaflet; *IBL*, inferior bridging leaflet; *SBL*, superior bridging leaflet; *RV*, right ventricle.

and color flow are still dependent on several cardiac cycles that require electrocardiographic gating with or without a breath hold to avoid motion artifact.

We chose to study those patients having patch repair of their LAVV because they invariably have complex pathologies responsible for the valve failure. Our data demonstrate that a precise correlation is possible between the surgical and 3D findings. Specific detail of commissural pathology is of importance in the planning of LAVV repair. Only the 3D technique can provide such information and help guide the surgeon toward a physiologic repair of the valve. In each case the 3D TEE morphology and pathology of the LAVV correlated with the surgical findings. For example, patient 5 had fusion of the superior bridging leaflet and mural leaflet to shortened thickened chordae, the nature of which could not be appreciated with 2D echocardiography. The 3D images, in conjunction with color Doppler scanning, demonstrated the unusual configuration of the valve, with no visible flow through that site in diastole. The site that would require patch enlargement of the LAVV could be identified by the 3D findings, as could the extent of poor leaflet coaptation in those patients with associated valve dysplasia or leaflet deficiency.

In many instances of postoperative LAVV regurgitation, it is difficult, by means of 2D techniques, to determine the precise role of a residual cleft. Three-dimensional echocardiography provides this information and helps determine whether a residual cleft can be implicated in the valve failure. Three-dimensional color Doppler scanning provides an instantaneous answer as to the precise location and extent of a regurgitant jet, again confirming a correlation between the observed pathology and function of the valve. Although there were no volumetric calculations as to the amount of regurgitation, subjectively, those with a larger vena contracta jet had more volume loading of their left ventricle. Indeed, there is a close correlation between the size of a vena contracta and absolute regurgitant volume.[19] The ability to rotate the images in 4D scanning (ie, in time) and view them either above or below the LAVV helped determine that the inferior regurgitant jet in patient 5 was related to the commissure between the inferior bridging leaflet and mural leaflet and not the secondary orifice.

Four of 5 patients had their 3D evaluations at the time of the operation, with the fifth having it a few weeks before rerepair. Data of this latter patient were subsequently presented to the surgical group during a regular preoperative meeting, with a decision as to the type of operation being planned before subsequent admission. Of note, the preoperative plan did not differ from its intraoperative counterpart. In patient 2 with the partial cleft, the surgeon reviewed the 3D findings immediately before the repair and determined that a leaflet extension would be necessary to improve the regurgitation. In the other cases from earlier in our experience, the surgical decision was based on the 2D findings in conjunction with surgical observations at the time of repair. One other advantage to those involved with echocardiography is that a 3D data set helps in the understanding of the 2D findings.

Study Limitations

Our current 3D technique requires TEE, which limits its pediatric use unless there is an active inpatient and outpatient TEE program established within an institution. The TEE probe, which is an adult Omniplane, has a manufacturer patient weight limit of greater than 15 kg, although in our experience it can be used safely above 12 kg. Currently, the pediatric probes of a similar design are driven manually and not electronically, hence limiting their value for 3D data sets in children who weigh less than 12 kg. This currently poses a problem because most patients requiring rerepair weigh less than this limit. Most likely, real-time 3D echocardiographic techniques will eventually replace the rotational approach; however, at present, this technique is still subject to limitations in smaller pediatric patients because of probe size and low transducer frequency. In addition, it is dependent on an adequate transthoracic window, which is frequently problematic both in the early postoperative period and with advancing age. Ideally, real-time TEE would provide the most accurate detail regarding mechanisms of LAVV failure. We did not attempt to address the role of 3D echocardiography in the evaluation of the LVOT in these patients but instead concentrated on the findings of the LAVV.

Conclusion

Three-dimensional TEE with an Omniplane probe provides accurate detail about LAVV pathology and function in pediatric patients weighing more than 12 kg with an AVSD. Data from these studies can aid in the planning of complex surgical repairs of the LAVV in children.

References

1. El Najdawi EK, Driscoll DJ, Puga FJ, Dearani JA, Spotts BE, Mahoney DW, et al. Operation for partial atrioventricular septal defect: a forty-year review. *J Thorac Cardiovasc Surg.* 2000;119:880-9.
2. Abbruzzese PA, Napoleone A, Bini RM, Annecchino FP, Merlo M, Parenzan L. Late left atrioventricular valve insufficiency after repair of partial atrioventricular septal defects: anatomical and surgical determinants. *Ann Thorac Surg.* 1990;49:111-4.
3. Alexi-Meskishvili V, Hetzer R, Dahnert I, Weng Y, Lange PE. Results of left atrioventricular valve reconstruction after previous correction of atrioventricular septal defects. *Eur J Cardiothorac Surg.* 1997;12:460-5.
4. Poirier NC, Williams WG, Van Arsdell GS, Coles JG, Smallhorn JF, Omran A, et al. A novel repair for patients with atrioventricular septal defect requiring reoperation for left atrioventricular valve regurgitation. *Eur J Cardiothorac Surg.* 2000;18:54-61.
5. Sittiwangkul R, Ma RY, McCrindle BW, Coles JG, Smallhorn JF. Echocardiographic assessment of obstructive lesions in atrioventricular septal defects. *J Am Coll Cardiol.* 2001;38:253-61.
6. Geva T, Ayres NA, Pignatelli RH, Gajarski RJ. Echocardiographic evaluation of common atrioventricular canal defects: a study of 206 consecutive patients. *Echocardiography.* 1996;13:387-400.
7. Zellers TM, Zehr R, Weinstein E, Leonard S, Ring WS, Nikaidoh H. Two-dimensional and Doppler echocardiography alone can adequately define preoperative anatomy and hemodynamic status before repair of complete atrioventricular septal defect in infants $<$ 1 year old. *J Am Coll Cardiol.* 1994;24:1565-70.
8. Sutaria N, Northridge D, Masani N, Pandian N. Three dimensional echocardiography for the assessment of mitral valve disease. *Heart.* 2000;84(suppl 2):II7–10.
9. Otsuji Y, Handschumacher MD, Schwammenthal E, Jiang L, Song JK, Guerrero JL, et al. Insights from three-dimensional echocardiography into the mechanism of functional mitral regurgitation: direct in vivo demonstration of altered leaflet tethering geometry. *Circulation.* 1997;96:1999-2008.

10. Sugeng L, Spenser KT, Mor-Avi V, DeCara JM, Bednarz JE, Weinert L, et al. Dynamic three-dimensional color flow Doppler: an improved technique for the assessment of mitral regurgitation. *Echocardiography.* 2003; 20:265-73.
11. van Son JA, Schneider P, Falk V. Repair of subaortic stenosis in atrioventricular canal with absent or restrictive interventricular communication by patch augmentation of ventricular septum, resuspension of atrioventricular valves, and septal myectomy. *Mayo Clin Proc.* 1997;72:220-4.
12. Hanley FL, Fenton KN, Jonas RA, Mayer JE, Cook NR, Wernovsky G, et al. Surgical repair of complete atrioventricular canal defects in infancy. Twenty-year trends. *J Thorac Cardiovasc Surg.* 1993;106: 387-94.
13. Bando K, Turrentine MW, Sun K, Sharp TG, Ensing GJ, Miller AP, et al. Surgical management of complete atrioventricular septal defects: a twenty-year experience. *J Thorac Cardiovasc Surg.* 1995;110:1543-52.
14. Vogel M, Ho SY, Lincoln C, Anderson RH. Transthoracic three-dimensional echocardiography for the assessment of straddling tricuspid or mitral valves. *Cardiol Young.* 2000;10:603-9.
15. Lange A, Mankad P, Walayat M, Palka P, Burns JE, Godman MJ. Transthoracic three-dimensional echocardiography in the preoperative assessment of atrioventricular septal defect morphology. *Am J Cardiol.* 2000;85:630-5.
16. Acar P, Laskari C, Rhodes J, Pandian N, Warner K, Marx G. Three-dimensional echocardiographic analysis of valve anatomy as a determinant of mitral regurgitation after surgery for atrioventricular septal defects. *Am J Cardiol.* 1999;83:745-9.
17. De Simone R, Glombitza G, Vahl CF, Meinzer HP, Hagl S. Three-dimensional color Doppler flow reconstruction and its clinical applications. *Echocardiography.* 2000;17:765-71.
18. Sugeng L, Weinert L, Thiele K, Lang RM. Real-time Three-dimensional echocardiography using a novel matrix array transducer. *Echocardiography.* 2003;20:623-35.
19. Li X, Shiota T, Delabays A, Teien D, Zhou X, Sinclair B, et al. Flow convergence flow rates from 3-dimensional reconstruction of color Doppler flow maps for computing transvalvular regurgitant flows without geometric assumptions: an in vitro quantitative flow. *J Am Soc Echocardiogr.* 1999;12:1035-44.